Note

Water production from food processing wastewaters using integrated membrane systems: A sustainable approach

• Roberto Castro-Muñoz* •
University of Chemistry and Technology Prague, Czech Republic/Instituto Politécnico Nacional, Mexico City, Mexico
*Corresponding author

• Vlastimil Fíla •
University of Chemistry and Technology Prague, Czech Republic

• Víctor M. Rodríguez-Romero • Jorge Yáñez-Fernández •
Instituto Politécnico Nacional, Mexico City, Mexico

DOI: 10.24850/j-tyca-2017-06-09

Abstract

Castro-Muñoz, R., Fíla, V., Rodríguez-Romero, V. M., & Yáñez-Fernández, J. (November-December, 2017). Water production from food processing wastewaters using integrated membrane systems: A sustainable approach. *Water Technology and Sciences* (in English), *8*(6), 129-136, DOI: 10.24850/j-tyca-2017-06-09.

This scientific note reviews current approaches for using membrane technology to treat wastewater from food processing, for example, as a means to produce water by recovering components with high added value. In addition, with regard to the availability of wastewater, processes that contain membranes have been shown to be advantageous in terms of treating waste, recovering solutes, and producing water. With regard to the latter, processes that contain membranes can be considered to be a sustainable methodology given the valorization of waste. Lastly, this note provides a brief general view emphasizing a real need to apply membrane technology in the food industry, and indicates that its application is undoubtedly to come.

Keywords: Wastes, microfiltration-ultrafiltration, nanofiltration, treatment, sustainability, recovery.

Resumen

Castro-Muñoz, R., Fíla, V., Rodríguez-Romero, V. M., & Yáñez-Fernández, J. (noviembre-diciembre, 2017). Producción de agua a partir de aguas residuales del procesamiento de alimentos mediante sistemas integrados de membrana: enfoque sustentable. Tecnología y Ciencias del Agua, *8(6), 129-136, DOI: 10.24850/j-tyca-2017-06-09.*

Esta nota científica revisa los enfoques actuales de la tecnología de membranas para el tratamiento de residuos del procesamiento de alimentos; por ejemplo, como vía para la producción de agua a través de la recuperación de componentes de alto valor agregado. Además, se ha demostrado que los procesos integrados de membrana pueden ofrecer la ventaja de realizar las siguientes tareas en términos de disposición de aguas residuales: tratamiento de residuos, recuperación de solutos y producción de agua. Esto último permite considerar a los procesos integrados de membrana como una metodología sustentable a través de la valorización de residuos. Por último, esta nota provee una breve visión general, resaltando que la aplicación de la tecnología de membranas en verdad es necesaria en la industria alimentaria y que seguramente su implementación real aún está por venir.

***Palabras clave**: residuos, microfiltración-ultrafiltración, nanofiltración, tratamiento, sustentabilidad, recuperación.*

Received: 01/12/2016
Accepted: 05/17/2017

Introduction: Food processing wastewaters

As it is well known, the waste disposal from agro-food industries is a current issue regarding environmental aspects. One of the most produced wastes in the food industry is the wastewater (WW), which is commonly derivatives from typical processing steps such as cooking, pre-cooking, treatment, washing and peeling. These WW present high organic contents associated to their high content of lixiviated compounds. Different types of methodologies have been applied to WW to decrease the chemical oxygen demand (COD) in the extracts. Methods, such as ozonation (Ternes *et al*., 2003), catalysis by using anaerobic reactor (Green *et al*., 2006), electrochemical treatment (Rajkumar & Palanivelu, 2004), coagulation, adsorption (Abdessemed, Nezzal, & Ben-Aim, 2000) and coupled methods (Lin & Peng, 1996), have been evaluated during last decades. Also, the recovery of specific components has been tested by solvent extraction (Okuda, Yamashita, Tanaka, Matsukawa, & Tanabe, 2009); however, these procedures are not potentially applied due to large quantities of supplies needed. Recently, pressure-driven membrane processes have been proposed for the treatment of food wastewaters (Van der Bruggen, Vandecasteele, Van Gestel, Doyen, & Leysen, 2003a; Van der Bruggen, Lejon, &Vandecasteele, 2003b). Specifically, micro (MF), ultra (UF) and nano (NF)- filtration processes were applied in Europe for the treatment of different wastewaters such as olive mill wastewater (OMWW) (Paraskeva, Papadakis, Tsarouchi, Kanellopoulou, & Koutsoukos, 2007; Russo, 2007; Galanakis, Tornberg, & Gekas, 2010; El-Abbassi, Khayet, & Hafidi, 2011; Cassano, Conidi, & Drioli, 2011), artichoke wastewater (AWW) (Conidi, Cassano, & Garcia-Castello, 2014), orange press liquor (OPL) (Conidi, Cassano, & Drioli, 2012) and winery sludge (Galanakis, Markouli, & Gekas, 2013). The last approaches were developed with the full purpose of recovering several valuable compounds; furthermore, these membrane operations offer different advantages in comparison with other methodologies widely tested (decantation separation, dissolved air flotation, de-emulsification, coagulation and flocculation) (Cheryan & Rajagopalan, 1998; Castro-Muñoz, Yáñez-Fernández, & Fíla, 2016a), such as: i) high productivities in terms of permeate fluxes, ii) absence of phase transition, iii) lack of additional phase, iv) easy operating conditions and v) high selectivity towards macro and micro-solutes (Conidi *et al*., 2014). However, some disadvantages can also be identified, e.g., the high cost of these pressure-driven processes is represented by the membrane, as well as the energy requirement that provides the driving force (Galanakis, Castro-Muñoz, Cassano, & Conidi, 2016), whereas their performances are limited by several factors such as concentration polarization, cake layer growth and fouling (Bubolz, Wille, Langer, & Werner, 2002). Indeed, these membrane processes are part of the "Universal Recovery Process" conformed by five stages according to Galanakis (2015): a) macroscopic pre-treatment, b) separation of macro and micro-molecules, c) extraction, d) isolation-purification, and e) product formation. Where MF, UF and NF can be used from the first to fourth stage. Currently, the most explored application of the membrane operations is focusing on the recovery of high-added value compounds from agro-food by-products. The main compounds that have been found in food processing WW are: polyphenols, carbohydrates (sugars), anthocyanins, proteins, pectin's and some other high-added-value compounds (Castro-Muñoz, Orozco-Álvarez, & Yáñez-Fernández, 2015a; Galanakis, 2015). In some cases, the final permeate coming from the membrane operations presents low organic load. These permeates seem to be streams which can be suitable for reuse as process water. This short communication provides a clear overview of the recent experimental cases about the membrane processes that were able to produce water streams as final samples.

• ISSN 0187-8336

Integrated membrane system developments on water production

The recovery of valuable components is an amazing and current challenge for the research and development (R & D). Like it previously stated, the membrane processes are considered as established and useful technologies for doing this recovery task (Galanakis, 2012). The innovation of these approaches is according to the design of the membrane processes. Different research groups have proposed the integrated membrane systems as via for the fractionation of several WW, as well as recovering the valuable compounds. The Integrated Membrane Process (IMP) is the use of more than one membrane operation in a sequential design; this approach leads to obtain different streams from a feeding stream. Indeed, the permeate obtained from a previous step is the feeding stream of a new membrane operation. For instance, Cassano, Conidi, Giorno and Drioli (2013) started to use IMPs for the fractionation of OMWWs, where the suspended solids and phenolic compounds were recovered. Otherwise, the final permeate obtained from the last membrane operation (NF) was also relevant due to a clear permeate with low Total Organic Carbon (TOC) concentration was produced (95 mg L^{-1}); table 1 shows the water stream obtained and the characteristics of the used IMP. Also, the authors suggested the reuse of this water stream as water process in the following oil extraction processes or the membrane cleaning procedure used for the treatment of this WW. The use of this clear permeate can be used as water for diafiltration to increase the phenolic content in the extract; if the concentration of this valuable compound is needed. The study provides three potential uses for the water stream recovered by a common effluent. Also, a clear permeate was also obtained from the concentration of flavanones and anthocyanins during the treatment of orange press liquor (OPL) through using an IMP, the final permeate presented low content in total soluble solids, which were identified as minerals and sugars. However, the permeate sample was not reported (Cassano, Conidi, & Ruby-Figueroa, 2014).

On the other hand, AWWs have also been evaluated as new source of recovering high-added value compounds (sugars and phenolics). Conidi *et al.* (2014) performed successfully the recovery step by using an IMP. The final water also presented enough characteristics to use the stream as process water or for membrane cleaning. According to the water characteristics reported in table 1, the reuse of this water is potentially suggested due to the minimal content of low molecular weight components that could not be identified by sensitive methodologies, like HPLC. Moreover, the same research group proposed another integrated membrane system to recover specific sugars (fructose, glucose, and sucrose) and polyphenols (apigenin, cynarin and chlorogenic acid) in two different streams from AWWs (Cassano, Conidi, Ruby-Figuera, & Castro-Muñoz, 2015). Likewise, a clear permeate free of sugars and phenolic compounds from the second NF step was obtained; the authors suggested the reuse of this stream for irrigation or recycling in the artichoke processing industry.

The main exploring studies of integrated membrane systems have been developed in Europe to provide a suitable solution for the disposal of OMWWs, AWWs, and OPL. Until 2015, there was no proposal to counteract the large amounts produced of WWs in the American continent by using membrane processes. The R & D is mainly focused on the Nixtamalization wastewaters (NWWs) regarding their disposal. This WW is produced by a common processing step given to the maize; which is carried out in almost all America, the Nixtamalization treatment. It is important to note that a production plant (in Mexico) with capacity of 600 Ton maize per day generates around 2000 m^3 of the extract (Salmeron-Alcocer *et al.*, 2003). If this WW production is interpolated to all Mexico or even to all America, it is clear the big challenge that we have to face. Nowadays, Castro-Muñoz, Orozco-Álvarez, Cerón-Montes, and Yáñez-Fernández (2015b) proposed the first attempt of membrane technology (MF) for the treatment of

ISSN 0187-8336 •

Table 1. Water streams obtained from the treatment of WWs by integrated membrane systems.

Agro-food by-product:	Integrated membrane process conformed by: (Membrane operation: MWCO)	Water sample obtained:	Characteristics of permeates:	Reference:
Olive mill wastewater	UF: 0.2 μm UF: 1 000 Da NF: > 97% $MgSO_4$ rejection		Low TOC: 95 mg l^{-1} Low TC: 100 mg l^{-1} Low TIC: 5 mg l^{-1} Hydroxytyrosol: 0 mg l^{-1} (N.D.) Caffeic acid: 0 mg l^{-1} (N.D.) p-cumaric acid: 0 mg l^{-1} (N.D.) Tyrosol: 0 mg l^{-1} (N.D.) Catechol: 0 mg l^{-1} (N.D.) Protocatechuic acid : 0 mg l^{-1} (N.D.) Total phenols: 0 mg l^{-1} (N.D.)	Cassano *et al.*, 2013
Orange press liquor	UF: 100 kDa NF: 25-50% Na_2SO_4 rejection	Not reported	Low TSS: 4.5 g 100 g^{-1}	Cassano *et al.*, 2014
Artichoke wastewaters	UF: 50 kDa NF: 400 Da, 85-95% Na_2SO_4 rejection NF: 150-300 Da, 96% $MgSO_4$ rejection	Not reported	Glucose: 0 mg l^{-1} (N.D.) Fructose: 0 mg l^{-1} (N.D.) Sucrose: 0 mg l^{-1} (N.D.) Cynarin: 0 mg l^{-1} (N.D.) Chlorogenic acid: 0 mg l^{-1} (N.D.) Apigenin-7-O-glucoside: 0 mg l^{-1} (N.D.)	Conidi *et al.*, 2014
Artichoke wastewaters	UF: 100 kDa NF: 400 Da, 85-95% Na_2SO_4 rejection NF: 150-300 Da	Not reported	Glucose: 0 mg l^{-1} (N.D.) Fructose: 0 mg l^{-1} (N.D.) Sucrose: 0 mg l^{-1} (N.D.) Cynarin: 0 mg l^{-1} (N.D.) Chlorogenic acid: 0 mg l^{-1} (N.D.) Apigenin-7-O-glucoside: 0 mg l^{-1} (N.D.)	Cassano *et al.*, 2015
Nixtamalization wastewaters	MF: 0.2 μm UF: 100 kDa UF: 1000 Da		Low TOC: 381 mg l^{-1} Low Carbohydrates content: 0.26 mg ml^{-1} Low turbidity: 3.78 NTU Free TSS: 0 ºBrix (N.D.)	Castro-Muñoz *et al.*, 2015a-d; Castro-Muñoz *et al.*, 2016b

TOC: Total Organic Carbon; TC: Total Carbon; TSS: Total Soluble Solids; TIC: Total Inorganic Carbon; N.D.: Not detected.

NWWs in order to decrease their TOC content. The evaluation to recover valuable compounds (carbohydrates) was also tested by using ultrafiltration (Castro-Muñoz, Cerón-Montes, Barragán-Huerta, & Yáñez-Fernández, 2015c). Finally, the sequential design of the membrane processes was successfully applied obtaining highlighted results; the rejection of calcium components was performed (Castro-Muñoz & Yáñez-Fernández, 2015d; Castro-Muñoz, Barragán-Huerta, Yáñez-Fernández, 2016b). Indeed, the final water stream was clear which presented low turbidity and TOC content (see table 1). The authors found high polyphenol content in the samples where additional recovery steps were suggested; however; this clear stream can be used as process water in following Nixtamalization processes.

Finally, table 1 shows the permeate samples obtained from Cassano *et al.* (2013) and Castro-Muñoz & Yáñez-Fernández (2015d) in their respective cases of study. Cassano *et al.* (2013) achieved to obtain a stream totally clear; whereas Castro-Muñoz produced a clear permeate with low turbidity. The difference of both studies can be attributed to the specific membranes used;

• ISSN 0187-8336

nanofiltration and ultrafiltration membranes; respectively. Nevertheless; the use of narrow pore size membrane (1 kDa) is also a useful tool because this specific barrier is considered as the border of nanofiltration (Galanakis, 2015). Thereby, we can see that few applications of IMPs have been successfully developed. This current proposal seems to be suitable for the reduction of WW, providing a feasible possibility for re-processed them. Indeed, the utilization of IMPs has come to solve the final disposal of common WWs in the European Union; it can be an amazing tool for America too. The objectives are perfectly aimed to:

- Treat the WWs to decrease their COD.
- Recover the high-added value compounds from the WWs.

The last subjects have been successfully achieved and demonstrated; however, an extra plus was also discovered, which could be strongly the most important: *The water production*. A sustainable scheme can be proposed according to this revision, as figure 1 shows.

The recovery of valuable compounds trough the WW treatment provides a result on reducing the COD in the by-products. This point of view can offer an outlook to the industries regarding waste disposal and economic aspects. The high-added value solutes (sugars, pectins, proteins, polyphenols) commonly recovered from wastes are of interest for food and pharmaceutical industries; the application of the membrane technology represents a feedback option at least economically. Also, the reuse of produced water is a real possibility to demonstrate a sustainability concept: *Industry-Environment-Society*. The integrated membrane systems represent a valuable methodology for making the complete task by developing a "*Sustainable Recovery Process*".

General remarks

The water care is a current problem that concerns to the society, while researchers are en-

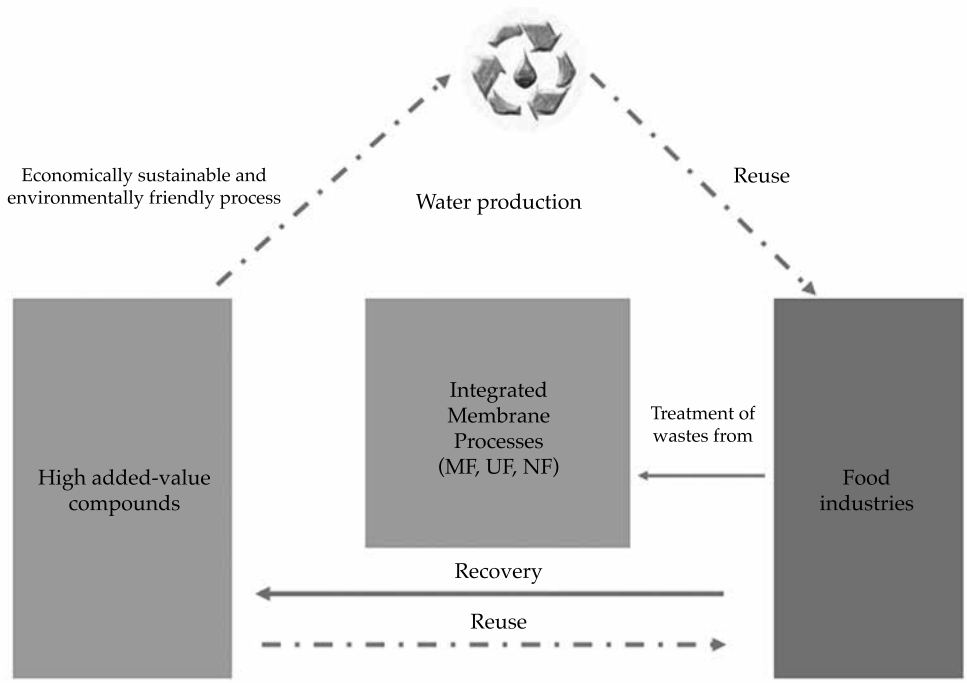

Figure 1. Sustainability of the IMPs through the water recovery.

ISSN 0187-8336 •

couraged to attend this global issue looking for new helpful technologies. At least, the treatment of food processing wastewaters can be solved if the application of membrane technology is well done. Also, the Food processing industries must start to consider their wastes as potential sources for useful components; the wine-making industry seems to be a consolidated trade that use its by-products for recovering valuable phenolic compounds (Crespo & Brazinha, 2010). Nowadays, R&D is looking for new sustainable methodologies and the revised studies demonstrate that the recovery of valuable solutes could offer the chance to obtain *water for recycling*. The IMP is a new development that has to continue being explored. Likewise, the future trends should be focused in this field because the food production demand is always increasing (Bennett, 2015). Finally, the economic investment concerns to the industries, the application of the IMP approaches is economical and environmentally sustainable, and their benefits will be reflected remarkably soon.

Abbreviations

Microfiltration: MF
Ultrafiltration: UF
Nanofiltration: NF
Wastewaters: WW
Olive mill wastewater: OMWW
Artichoke wastewater: AWW
Orange press liquor: OPL
Nixtamalization wastewaters: NWW
Chemical oxygen demand: COD
Integrated membrane process: IMP
Molecular weight cut-off: MWCO
Total organic carbon: TOC
Total soluble solids: TSS
Total carbon: TC
Total inorganic carbon: TIC
Not detected: N.D.

Acknowledgments

R. Castro-Muñoz acknowledges the European Commission - Education, Audiovisual and Culture Executive Agency (EACEA) for his PhD scholarship under the program: Erasmus Mundus Doctorate in Membrane Engineering-EUDIME (FPA No 2011-0014, Edition V, http:/eudime.unical.it). This work was partially supported by the Operational Program Prague-Competitiveness (CZ.2.16/3.1.00/24501), "National Program of Sustainability"(NPU I LO1613) MSMT-43760/2015, Czech Science Foundation (Grant GACR No. 15-06479S) and financial support from specific university research (IGA 2017, MSMT No 20-SVV/2017).

References

Abdessemed, D., Nezzal, G., & Ben-Aim, R. (2000). Coagulation-adsorption- ultrafiltration for wastewater treatment and reuse. *Desalination, 113*, 307-314. Recovered from http://www.sciencedirect.com/science/article/pii/S0011916400900298.

Bennett, A. (2015). Advances in filtration systems for wastewater treatment. *Filtration + Separation, 52*(5), 28-33. Recovered from http://www.sciencedirect.com/science/article/pii/S0015188215302226.

Bubolz, M., Wille, M., Langer, G., & Werner, U. (2002). The use of dean vortices for cross-flow microfiltration: Basic principles and further investigation. *Separation and Purification Technology*, 26, 81-89. Recovered from http://www.sciencedirect.com/science/article/pii/S1383586601001198.

Cassano, A., Conidi, C., & Drioli, E. (2011). Comparison of the performance of UF membranes in olive mill wastewaters treatment. *Water Research*, *45*, 3197-3204. Recovered from http://www.sciencedirect.com/science/article/pii/S004313541100159X.

Cassano, A., Conidi, C., Giorno, L. & Drioli, E. (2013). Fractionation of olive mill wastewaters by membrane separation techniques. *Journal of Hazardous Materials, 248–249*, 185–193. Recovered from http://www.sciencedirect.com/science/article/pii/S0304389413000113.

Cassano, A., Conidi, C., & Ruby-Figueroa, R. (2014). Recovery of flavonoids from orange press liquor by an integrated membrane process. *Membranes*, *4*, 509–524. Recovered from http://www.mdpi.com/2077-0375/4/3/509.

Cassano, A., Conidi, C., Ruby-Figueroa, R., & Castro-Muñoz, R. (2015). A two-step nanofiltration process for the production of phenolic-rich fractions from aqueous artichoke extracts. *International Journal of Molecular Sciences*, *16*, 8968-8987. Recovered from http://www.mdpi.com/1422-0067/16/4/8968.

Castro-Muñoz, R., Orozco-Álvarez, C., & Yáñez-Fernández, J. (2015a). Recovery of bioactive compounds from food processing wastewaters by ultra and nanofiltration: A review. *Advances in Bioresearch*, *6*(3), 152-158. Recovered from http://www.soeagra.com/abr_may2015.html.

• ISSN 0187-8336

Castro-Muñoz, R., Orozco-Álvarez, C., Cerón-Montes, G. I., & Yáñez-Fernández, J. (2015b). Characterization of the microfiltration process for the treatment of nixtamalization wastewaters. *Ingeniería Agricola y Biosistemas*, *7*(1), 23-34. Recovered from http://www.chapingo.mx/revistas/inagbi/contenido.php?id_revista_numero=198.

Castro-Muñoz, R., Cerón-Montes, G. I., Barragán-Huerta, B. E., & Yáñez-Fernández, J. (2015c). Recovery of carbohydrates from nixtamalization wastewaters (Nejayote) by ultrafiltration. *Revista Mexicana de Ingeniería Química*, *14*(3), 735-744. Recovered from http://www.redalyc.org/articulo.oa?id=62043088014.

Castro-Muñoz, R., & Yáñez-Fernández, J. (2015d). Valorization of nixtamalization wastewaters by integrated membrane process. *Food and Bioproducts Processing*, *95*, 7-18. Recovered from http://www.sciencedirect.com/science/article/pii/S0960308515000346.

Castro-Muñoz, R., Yáñez-Fernández, J., & Fíla, V. (2016a). Phenolic compounds recovered from agro-food by-products using membrane technologies: An overview. *Food Chemistry*, *213*, 753–762. Recovered from http://www.sciencedirect.com/science/article/pii/S0308814616310524.

Castro-Muñoz, R., Barragán-Huerta, B. E., & Yáñez-Fernández, J. (2016b). The use of nixtamalization waste waters clarified by ultrafiltration for production of a fraction rich in phenolic compounds. *Waste and Biomass Valorization*, *7*(5), 1167-1176. Recovered from https://link.springer.com/article/10.1007%2Fs12649-016-9512-6.

Cheryan, M., & Rajagopalan, N. (1998). Membrane processing of oily streams. Wastewater treatment and waste reduction. *Journal of Membrane Science*, *151*, 13-28. Recovered from http://www.sciencedirect.com/science/article/pii/S0376738898001902.

Conidi, C., Cassano, A., & Garcia-Castello, E. (2014). Valorization of artichoke wastewaters by integrated membrane process. *Water Research*, *48*, 363-374. Recovered from http://www.sciencedirect.com/science/article/pii/S0043135413007392.

Conidi, C., Cassano, A., & Drioli, E. (2012). Recovery of phenolic compounds from orange press liquor by nanofiltration. *Food and Bioproducts Processing*, *90*, 867-874. Recovered from http://www.sciencedirect.com/science/article/pii/S0960308512000594.

Crespo, J. G., & Brazinha, C. (2010). Membrane processing: Natural antioxidants from winemaking by-products. *Filtration + Separation*, *47*, 32-35. Recovered from http://www.sciencedirect.com/science/article/pii/S0015188210700793.

El-Abbassi, A., Khayet, M., & Hafidi, A. (2011). Micellar enhanced ultrafiltration process for the treatment of olive mill wastewater. *Water Research*, *45*, 4522-4530. Recovered from http://www.sciencedirect.com/science/article/pii/S0043135411003186.

Galanakis, C. M., Tornberg, E., & Gekas, V. (2010). Clarification of high-added value products from olive mill wastewaters. *Journal of Food Engineering*, *99*, 190-197. Recovered from http://www.sciencedirect.com/science/article/pii/S0260877410000907.

Galanakis, C. M. (2012). Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications. *Trends in Food Science and Technology*, *26*, 68-87. Recovered from http://www.sciencedirect.com/science/article/pii/S0924224412000532.

Galanakis, C. M., Markouli, E., & Gekas, V. (2013). Recovery and fractionation of different phenolic classes from winery sludge using ultrafiltration. *Separation and Purification Technology*, *107*, 245–251. Recovered from http://www.sciencedirect.com/science/article/pii/S1383586613000567.

Galanakis, C. M. (2015). Separation of functional macromolecules and micromolecules: From ultrafiltration to the border to nanofiltration. *Trends in Food Science and Technology*, *42*, 44-63. Recovered from http://www.sciencedirect.com/science/article/pii/S092422441400260X.

Galanakis, C. M., Castro-Muñoz, R., Cassano, R., & Conidi, C. (2016). Recovery of high-added-value compounds from food wastes by membrane technology. In: *Membrane Technologies for Biorefining*. Figoli, A., Cassano, A., & Basile, A. (eds.). *Elsevier*, 190-215. Recovered from http://www.sciencedirect.com/science/article/pii/B9780081004517000086.

Green, M., Shaul, N., Beliavski, M., Sabbah, I., Ghattas, B., & Tarre, S. (2006). Minimizing land requirement and evaporation in small wastewater treatment systems. *Ecological Engineering*, *26*(3), 266-271. Recovered from http://www.sciencedirect.com/science/article/pii/S0925857405002235.

Lin, S. H., & Peng, C. F. (1996). Continuous treatment of textile wastewater by combined coagulation, electrochemical oxidation and activated sludge. *Water Research*, *30*(3), 587-592. Recovered from http://www.sciencedirect.com/science/article/pii/0043135495002103.

Okuda, T., Yamashita, N., Tanaka, H., Matsukawa, H., & Tanabe, K. (2009). Development of extraction method of pharmaceuticals and their occurrences found in Japanese wastewater treatment plants. *Environmental International*, *35*(5), 815-820. Recovered from http://www.sciencedirect.com/science/article/pii/S0160412009000075.

Paraskeva, C. A., Papadakis, V. G., Tsarouchi, E., Kanellopoulou, D. G., & Koutsoukos, P. G. (2007). Membrane processing for olive mill wastewater fractionation. *Desalination*, *213*, 218-229. Recovered from http://www.sciencedirect.com/science/article/pii/S0011916407003244.

Rajkumar, D., & Palanivelu, K. (2004). Electrochemical treatment of industrial wastewater. *Journal of*

Hazardous Materials, *113*, 123-129. Recovered from http://www.sciencedirect.com/science/article/pii/S0304389404003619.

Russo, C. (2007). A new membrane process for the selective fractionation and total recovery of polyphenols, water and organic substances for vegetation waters (VW). *Journal of Membrane Science*, *288*, 239-246. Recovered from http://www.sciencedirect.com/science/article/pii/S0376738806007599.

Salmeron-Alcocer, A., Rodriguez-Mendoza, N., Pineda-Santiago, S., Cristiani-Urbina, E., Juarez-Ramirez, C., Ruiz-Ordaz, N., & Galindez-Mayer, J. (2003). Aerobic treatment of maize processing wastewater (nejayote) in a single stream multistage reactor. *Journal of Environmental Engineering and Science*, *2*, 401-406. Recovered from http://www.nrcresearchpress.com/doi/abs/10.1139/s03-046#.VoSIIJPhDwc.

Ternes, T. A., Stuber, J., Herrmann, N., McDowell, D., Ried, A., Kampmann, M., & Teiser, B. (2003). Ozonation: A tool for removal of pharmaceuticals, contrast media and musk fragrances from wastewaters. *Water Research*, *37*, 1976-1982. Recovered from http://www.sciencedirect.com/science/article/pii/S0043135402005705.

Van der Bruggen, B., Vandecasteele, C., Van Gestel, T., Doyen, W., & Leysen, R. (2003a). A review of pressure-driven membrane processes in wastewater treatment and drinking water production. *Environmental progress*, *2*(1), 46-56. Recovered from http://onlinelibrary.wiley.com/doi/10.1002/ep.670220116/abstract.

Van der Bruggen, B., Lejon, L., & Vandecasteele, C. (2003b). Reuse, treatment, and discharge of the concentrate of pressure-driven membrane processes. *Environmental Science and Technology*, *37*(17), 3733-3738. Recovered from http://pubs.acs.org/doi/abs/10.1021/es020175.

Author´s institutional address

Ph.D. Roberto Castro-Muñoz

University of Chemistry and Technology Prague
Technická 5, 166 28 Prague 6, Czech Republic
Phone: +420 220 444 018
castromr@vscht.cz
food.biotechnology88@gmail.com

Instituto Politécnico Nacional
Unidad Profesional Interdisciplinaria de Biotecnología
Laboratorio de Biotecnología Alimentaria
Av. Acueducto s/n, Col. Barrio La Laguna, Ticoman, 07340
Ciudad de México, Mexico
Phone: +52 55 57296300, ext. 56477

Ph.D. Vlastimil Fíla

University of Chemistry and Technology Prague
Technická 5, 166 28 Prague 6, Czech Republic
Phone: +420 (220) 444 018
filav@vscht.cz

M.Sc. Víctor M. Rodríguez-Romero
Ph.D. Jorge Yáñez-Fernández

Instituto Politécnico Nacional
Unidad Profesional Interdisciplinaria de Biotecnología
Laboratorio de Biotecnología Alimentaria
Av. Acueducto s/n, Col. Barrio La Laguna, Ticoman, 07340
Ciudad de México, México
Phone: +52 (55) 57296 300, ext. 56477
vrodriguezro@ipn.mx
jyanezfe@ipn.mx

• ISSN 0187-8336